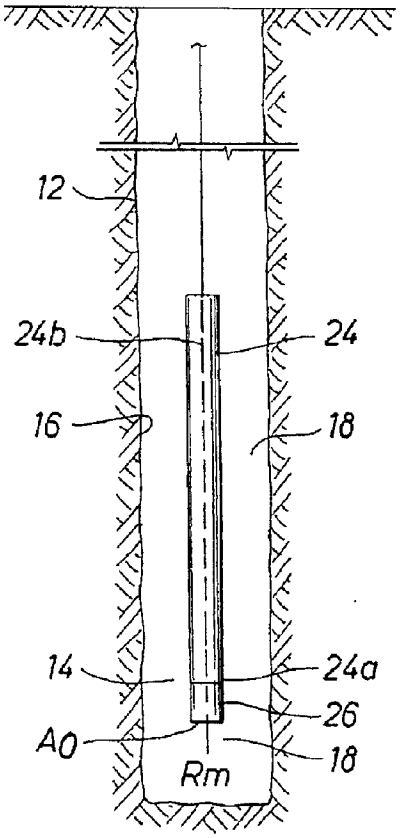


FIG. 1
(Prior Art)

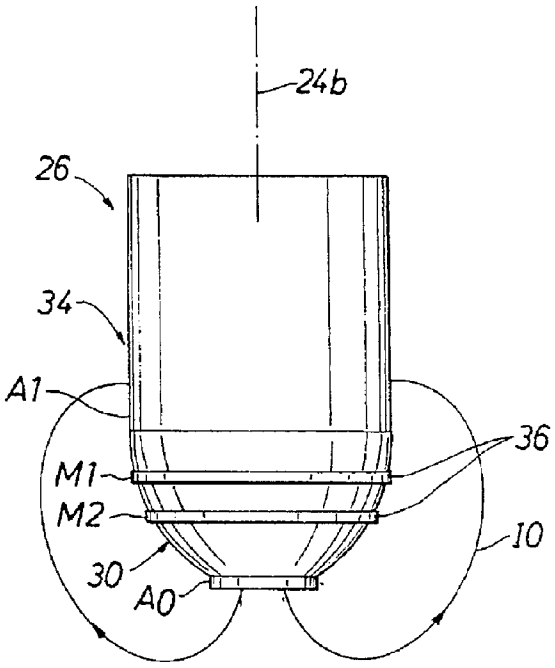


FIG. 2
(Prior Art)

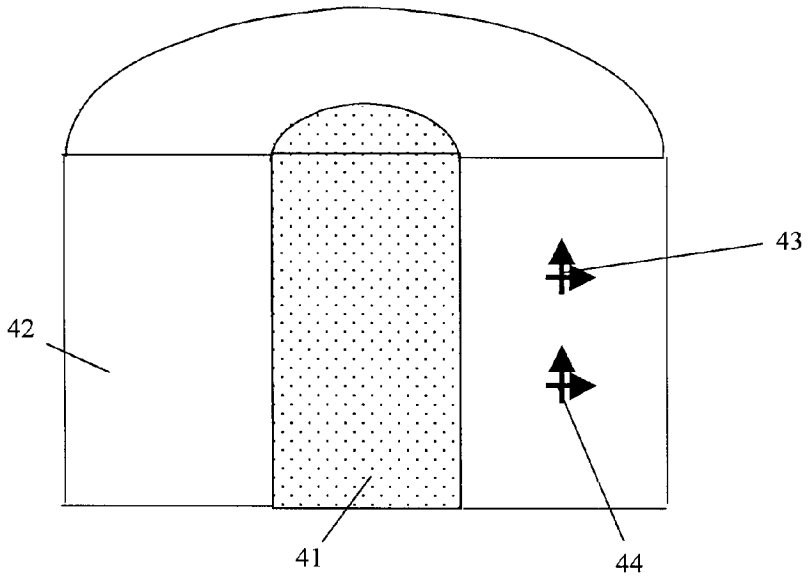


FIG. 3

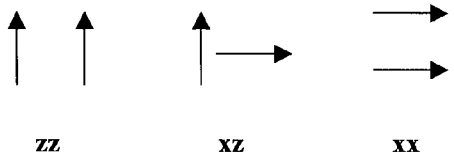


FIG. 4

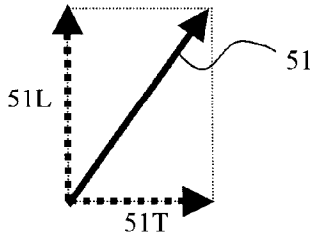


FIG. 5

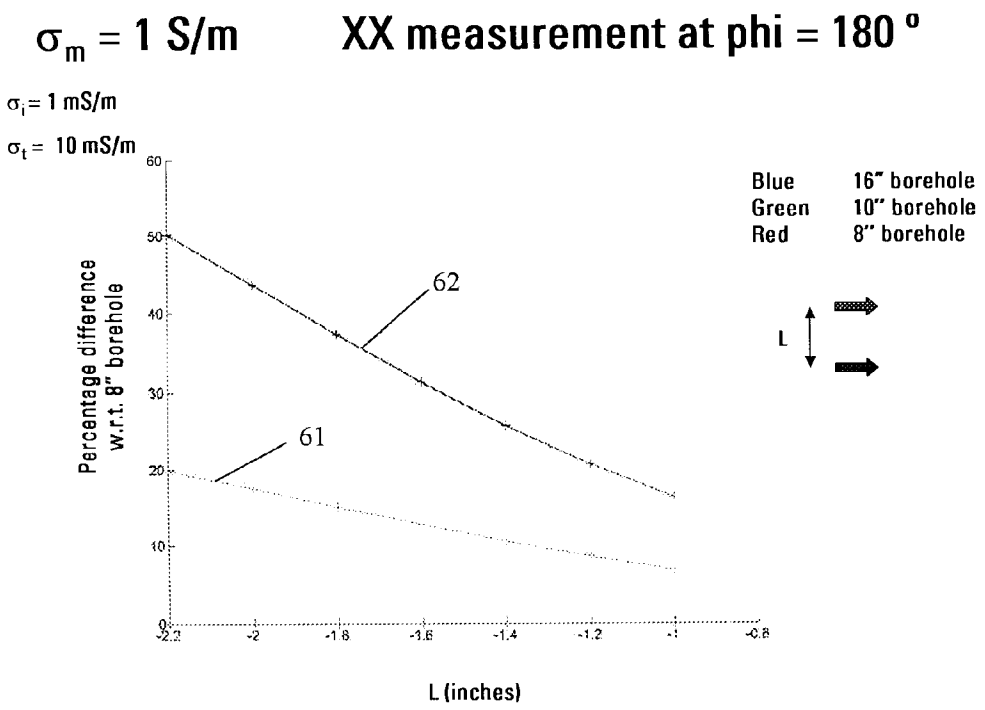

σm = 1 S/m
XX measurement at phi = 180 °
σi = 1 mS/m
σt = 10 mS/m
Blue 16" borehole
Green 10" borehole
Red 8" borehole
L
62
61
Percentage difference w.r.t. 8" borehole
60
50
40
30
20
10
0
-2.2
-2
-1.8
-1.6
-1.4
-1.2
-1
-0.8
L (inches)

FIG. 6

σ_m = 1 S/m ZZ measurement at phi = 180 °

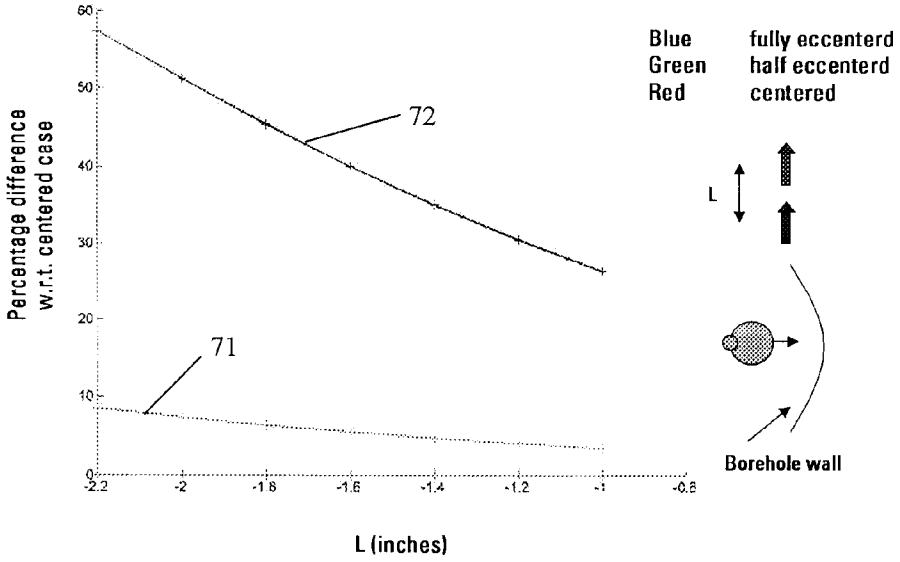


FIG. 7

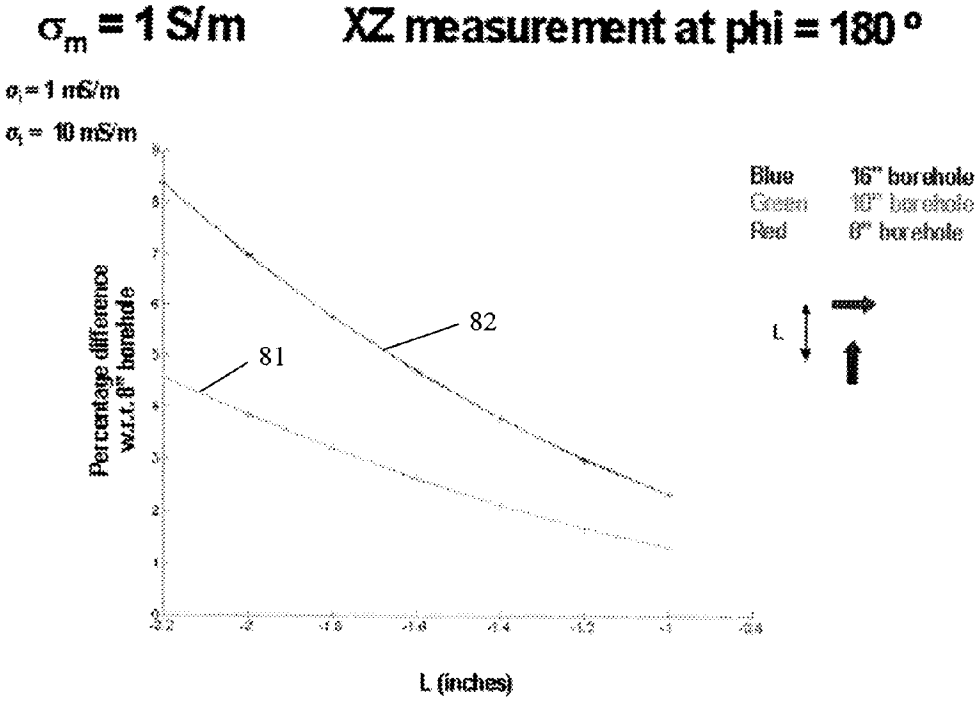

σm = 1 S/m
XZ measurement at phi = 180 °
σt = 1 mS/m
σt = 10 mS/m
Blue 16" borehole
Green 10" borehole
Red 8" borehole
L
82
81
Percentage difference w.r.t. 8" borehole
L (inches)

FIG. 8

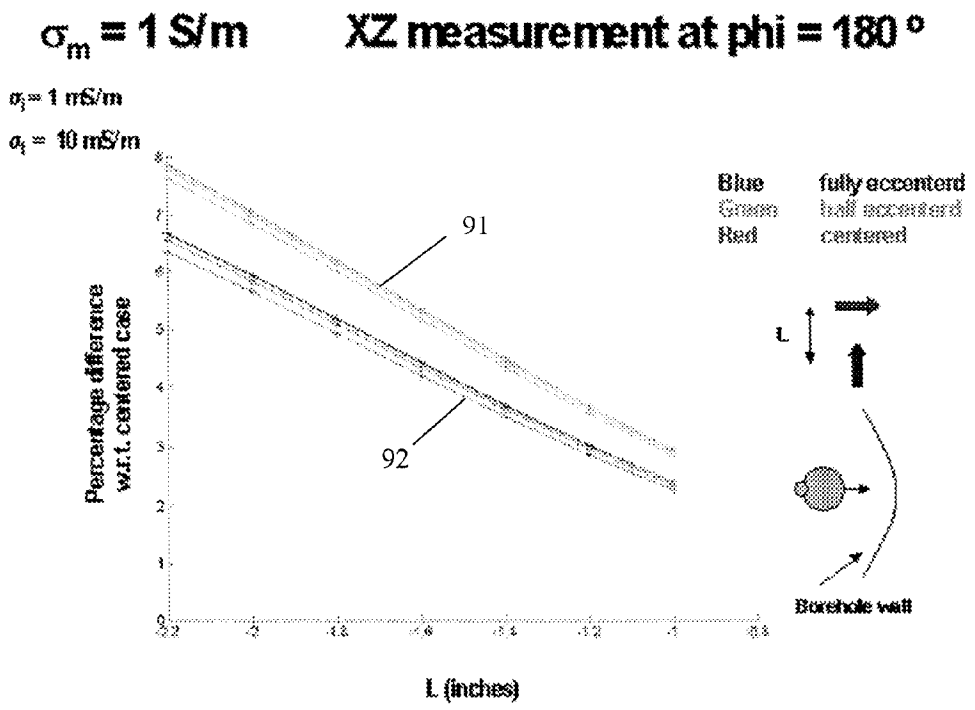

σm = 1 S/m
XZ measurement at phi = 180 °
σi = 1 mS/m
σt = 10 mS/m
Blue fully eccentered
Green half eccentered
Red centered
91
92
L
Borehole wall
Percentage difference w.r.t. centered case
L (inches)

FIG. 9

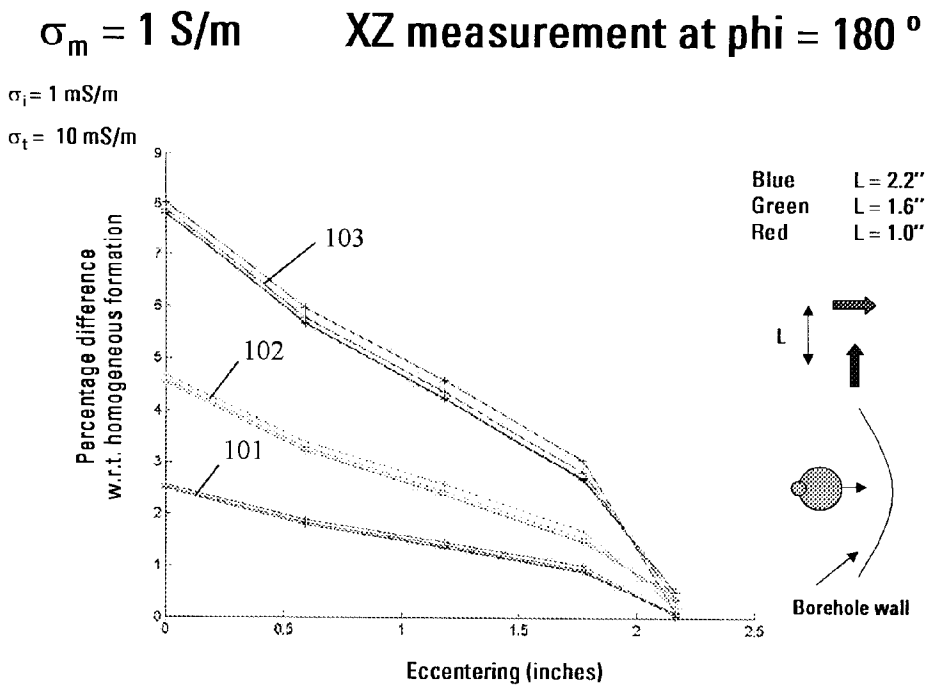

σm = 1 S/m
XZ measurement at phi = 180 °
σi = 1 mS/m
σt = 10 mS/m
Percentage difference w.r.t. homogeneous formation
103
102
101
Blue L = 2.2"
Green L = 1.6"
Red L = 1.0"
L
Borehole wall
Eccentering (inches)

FIG. 10

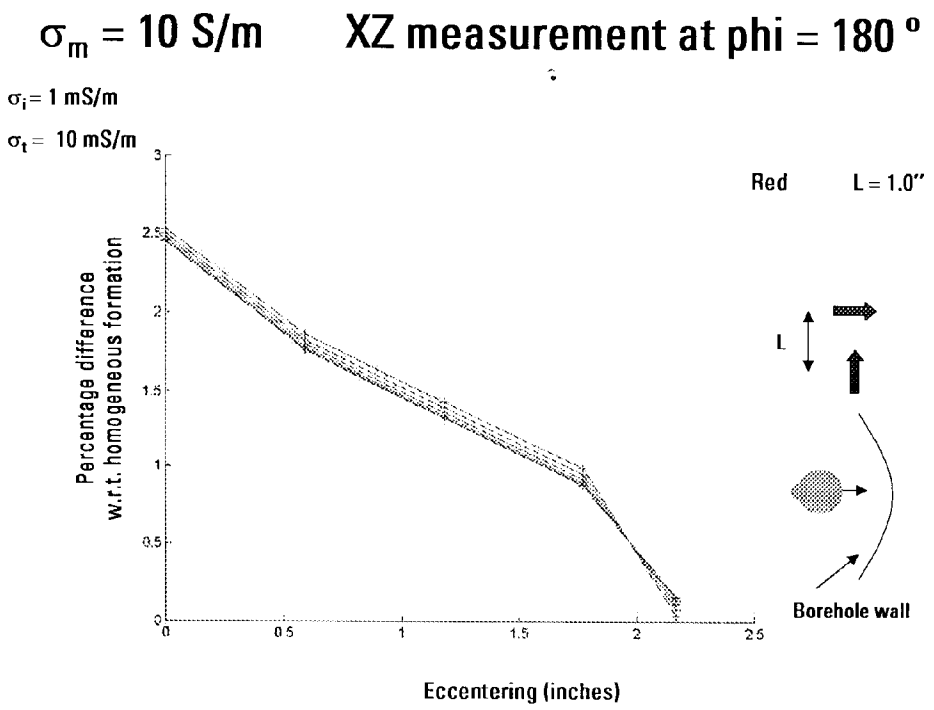

σm = 10 S/m
XZ measurement at phi = 180 °
σi = 1 mS/m
σt = 10 mS/m
Red
L = 1.0"
L
Borehole wall
Percentage difference w.r.t. homogeneous formation
Eccentering (inches)
0
0.5
1
1.5
2
2.5
3

FIG. 11

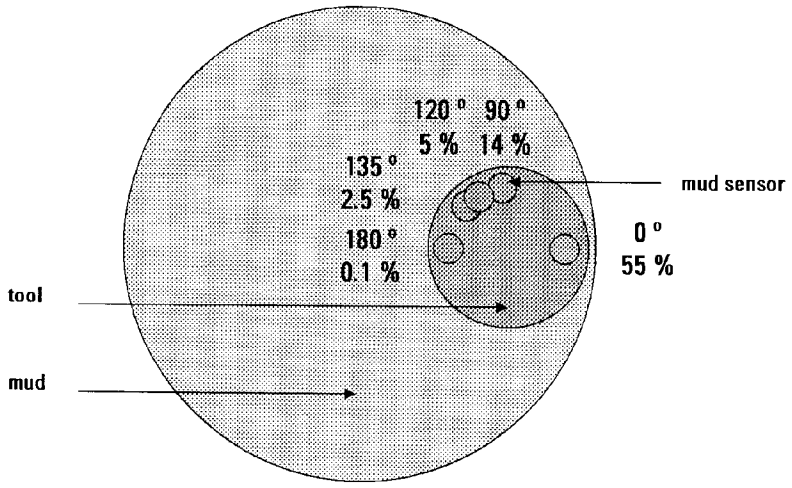


FIG. 12

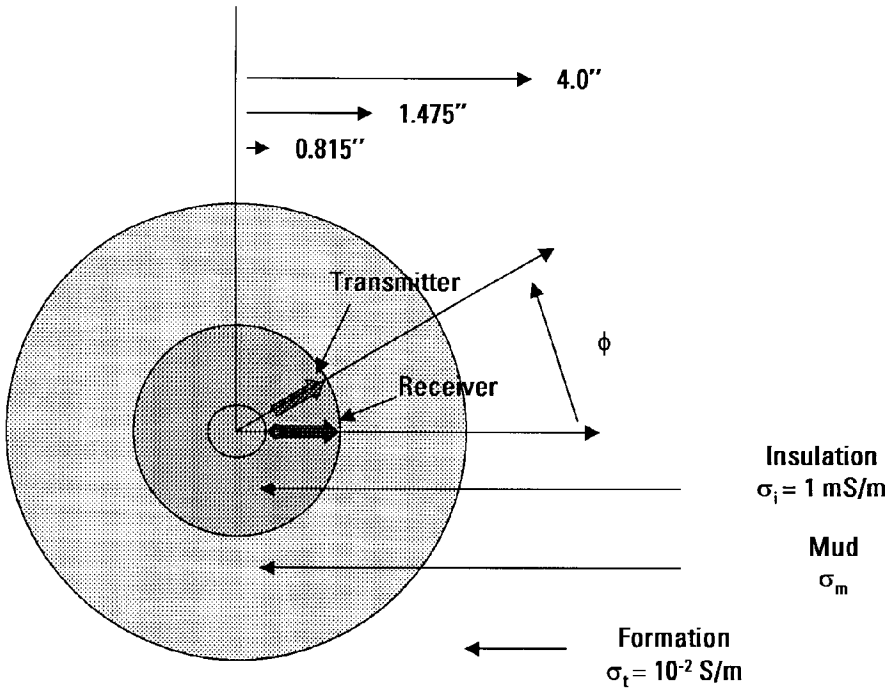

4.0"
1.475"
0.815"
Transmitter
Receiver
ϕ
Insulation
σ_i = 1 mS/m
Mud
σ_m
Formation
$\sigma_t = 10^{-2}$ S/m

FIG. 13

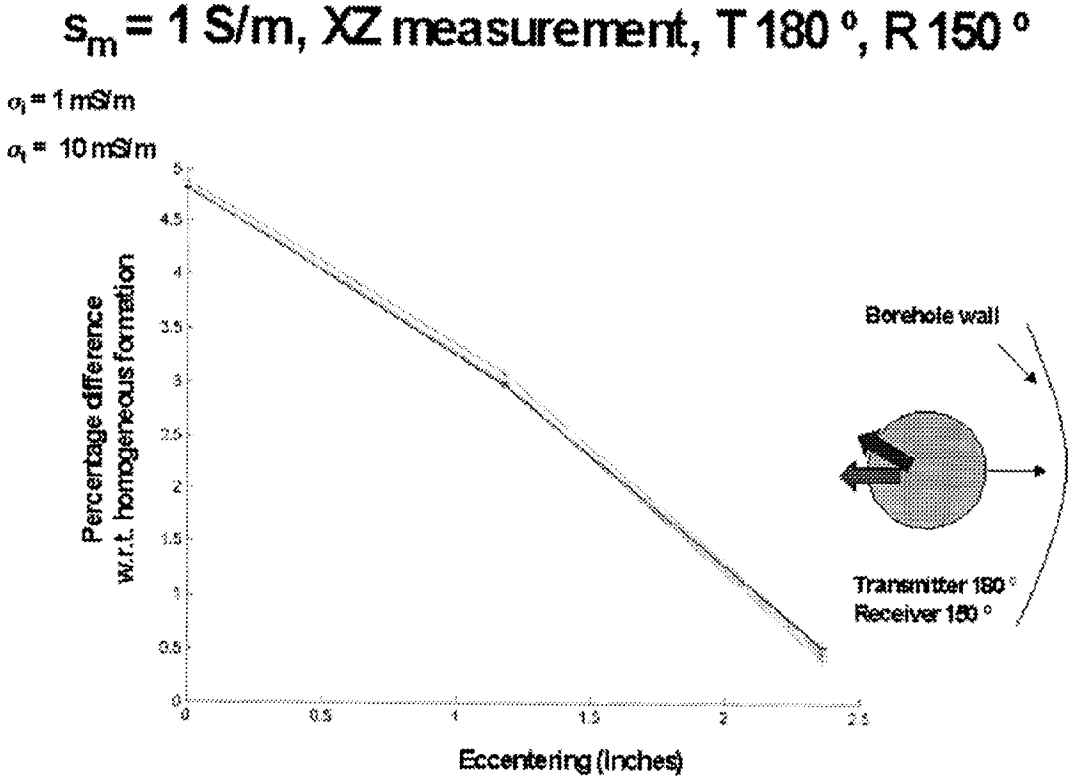

s_m = 1 S/m, XZ measurement, T 180 °, R 150 °
σ_i = 1 mS/m
σ_i = 10 mS/m
Percentage difference w.r.t. homogeneous formation
Eccentering (Inches)
Borehole wall
Transmitter 180 °
Receiver 150 °

FIG. 14

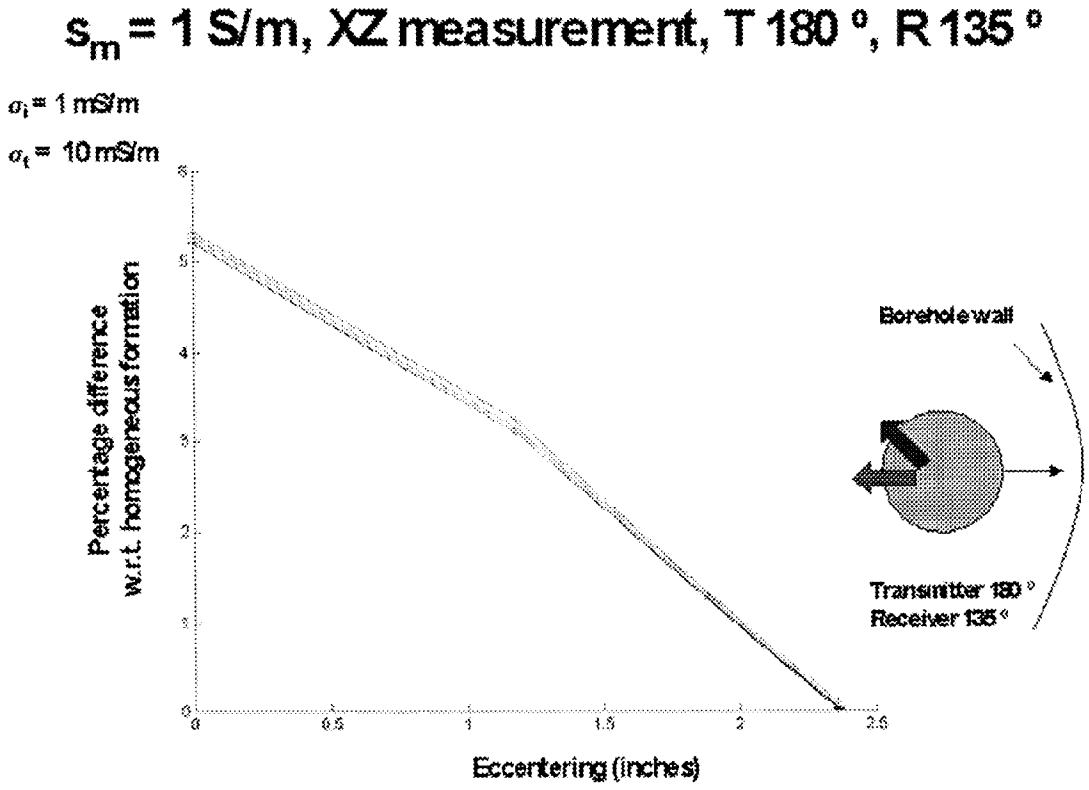

s_m = 1 S/m, XZ measurement, T 180 °, R 135 °
σ_t = 1 mS/m
σ_t = 10 mS/m
Percentage difference w.r.t. homogeneous formation
Eccentering (inches)
Borehole wall
Transmitter 180 °
Receiver 135 °

FIG. 15

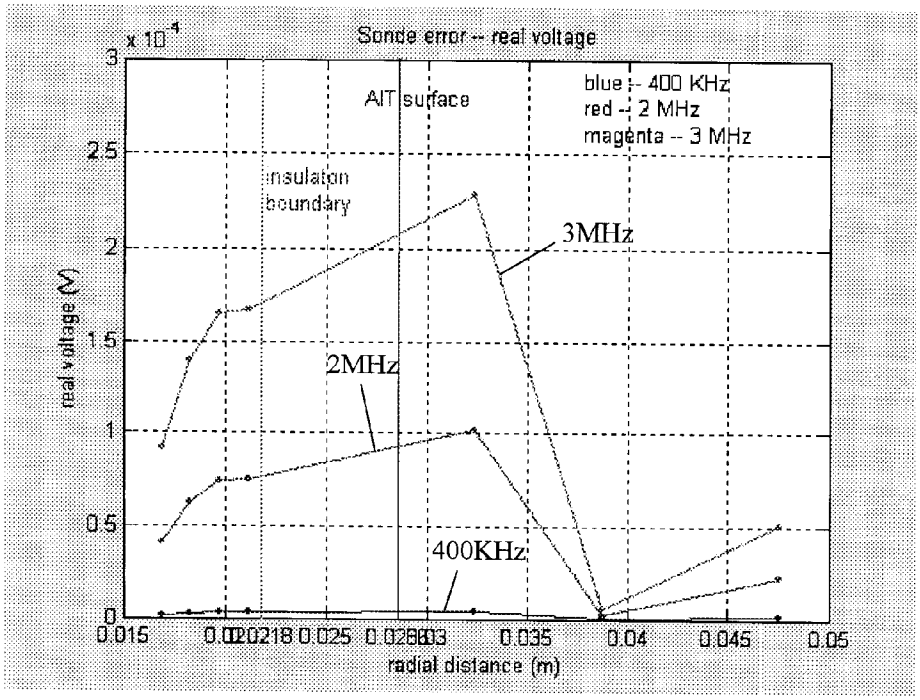

Sonde error -- real voltage
x 10^-4
AIT surface
blue -- 400 KHz
red -- 2 MHz
magenta -- 3 MHz
insulation boundary
3MHz
2MHz
400KHz
real voltage (V)
radial distance (m)
3
2.5
2
1.5
1
0.5
0
0.015
0.04
0.045
0.05

FIG. 16

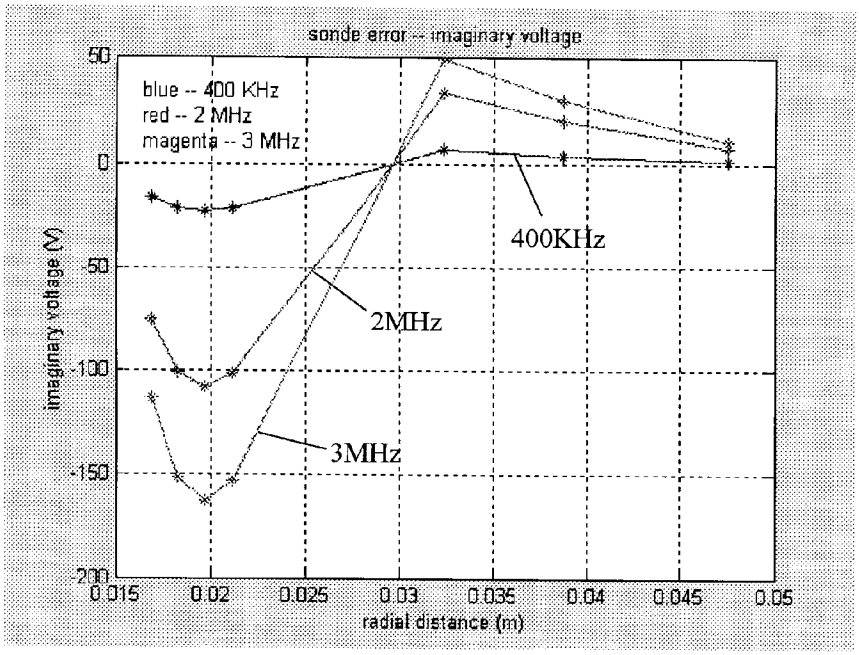

sonde error -- imaginary voltage
blue -- 400 KHz
red -- 2 MHz
magenta -- 3 MHz
400KHz
2MHz
3MHz
imaginary voltage (V)
radial distance (m)
50
0
-50
-100
-150
-200
0.015
0.02
0.025
0.03
0.035
0.04
0.045
0.05

FIG. 17

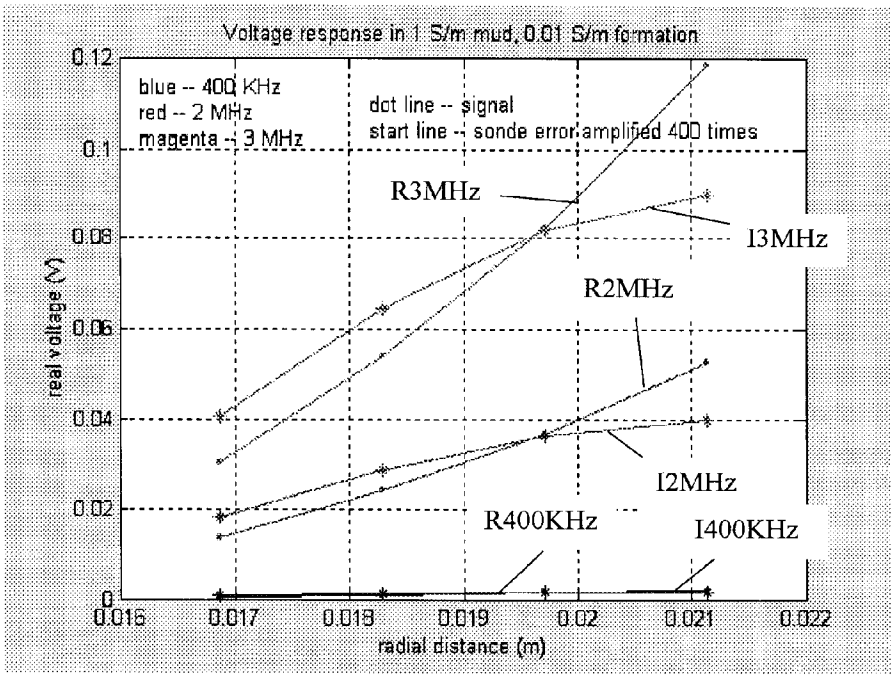
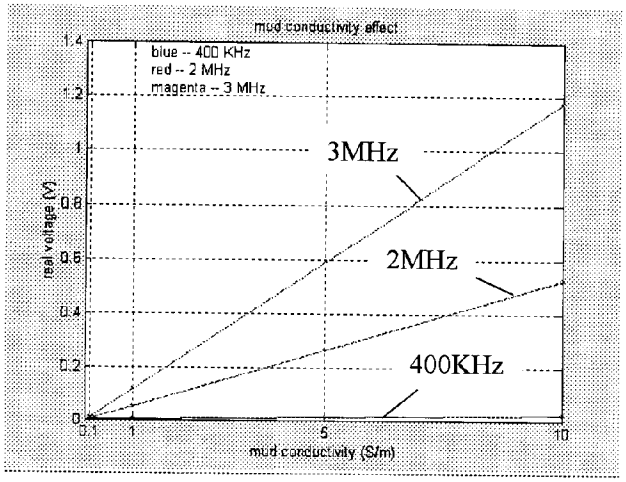
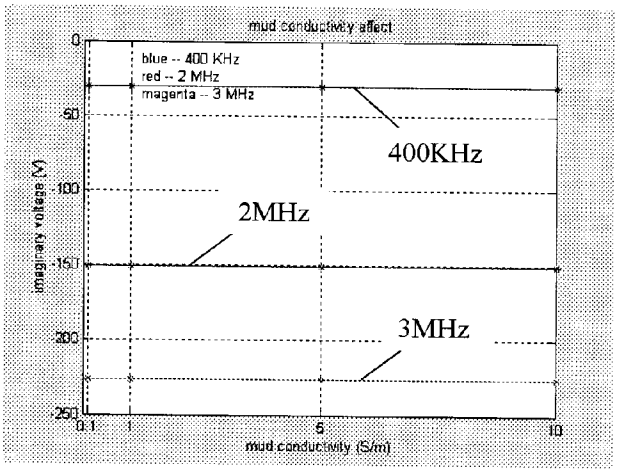

Voltage response in 1 S/m mud, 0.01 S/m formation
blue -- 400 KHz
red -- 2 MHz
magenta -- 3 MHz
dot line -- signal
start line -- sonde error amplified 400 times
R3MHz
I3MHz
R2MHz
I2MHz
R400KHz
I400KHz
real voltage (V)
radial distance (m)
0.12
0.1
0.08
0.06
0.04
0.02
0
0.016
0.017
0.018
0.019
0.02
0.021
0.022

FIG. 18


mud conductivity effect
blue -- 400 KHz
red -- 2 MHz
magenta -- 3 MHz
3MHz
2MHz
400KHz
real voltage (V)
mud conductivity (S/m)

(A)


mud conductivity effect
blue -- 400 KHz
red -- 2 MHz
magenta -- 3 MHz
400KHz
2MHz
3MHz
imaginary voltage (V)
mud conductivity (S/m)

(B)

FIG. 19

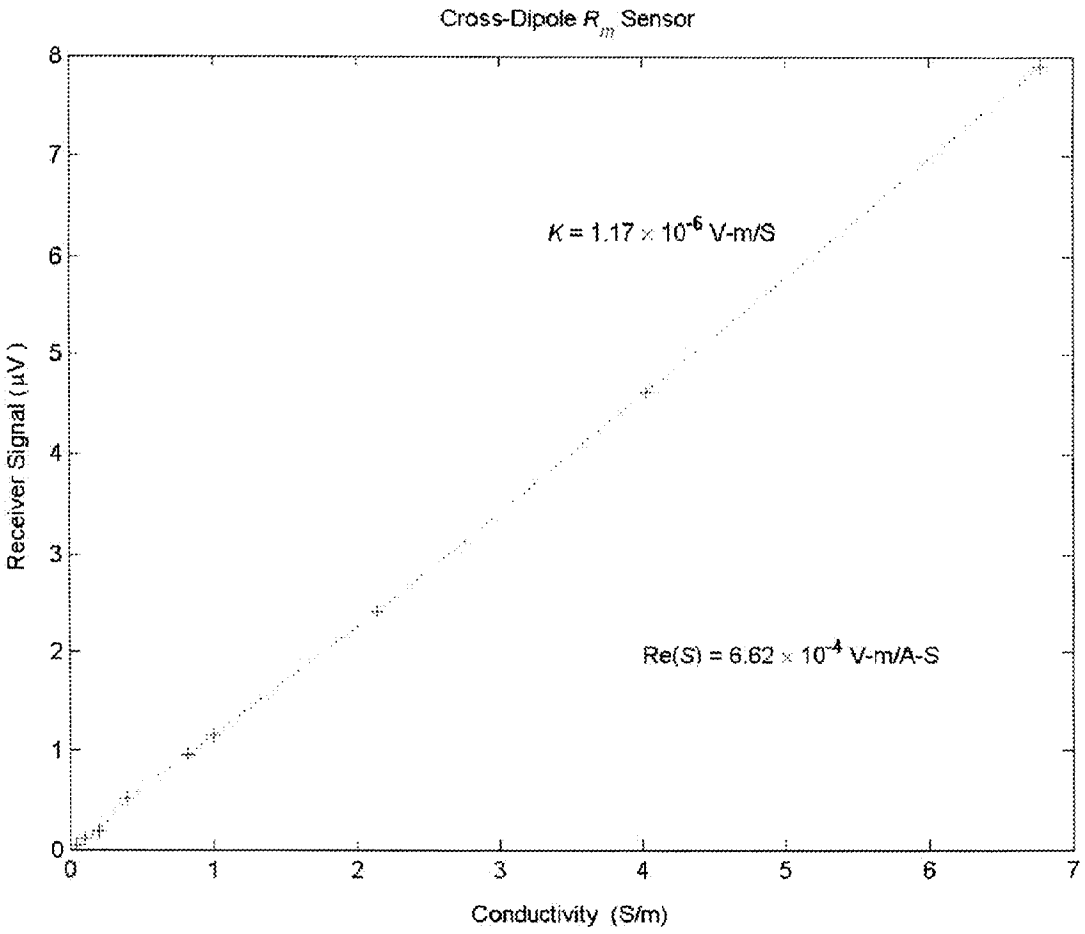
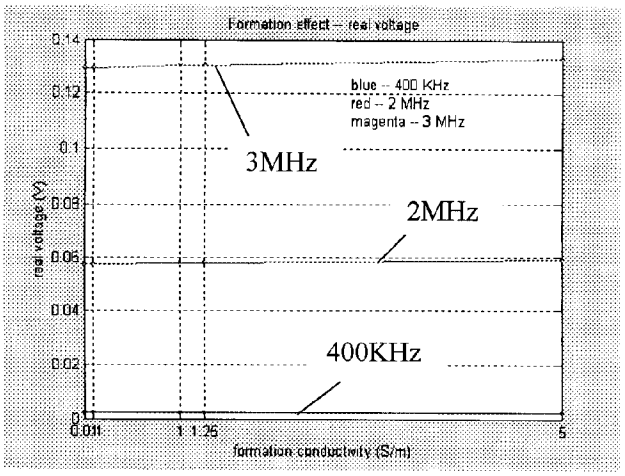
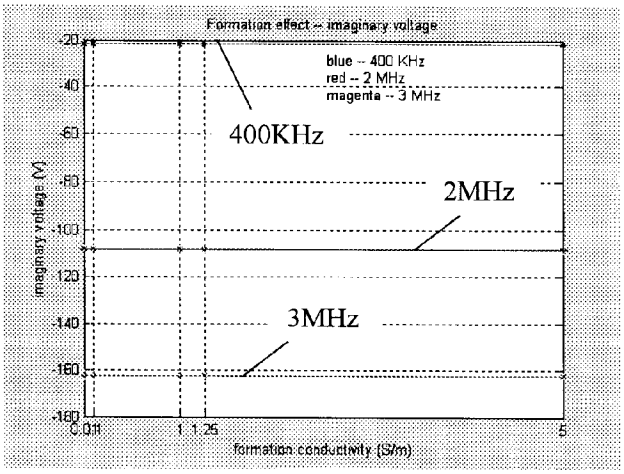

Cross-Dipole R_{zz} Sensor
$K = 1.17 \times 10^{-6}$ V-m/S
$Re(S) = 6.62 \times 10^{-4}$ V-m/A-S
Receiver Signal (μV)
Conductivity (S/m)
0
1
2
3
4
5
6
7
8

FIG. 19C

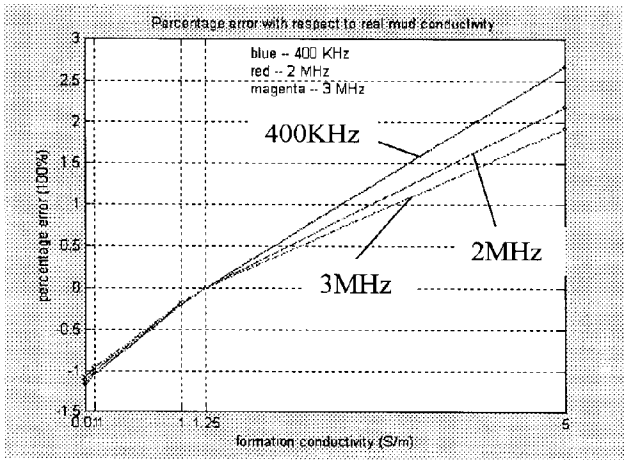

Formation effect -- real voltage
blue -- 400 KHz
red -- 2 MHz
magenta -- 3 MHz
3MHz
2MHz
400KHz
real voltage (V)
formation conductivity (S/m)

(A)


Formation effect -- imaginary voltage
blue -- 400 KHz
red -- 2 MHz
magenta -- 3 MHz
400KHz
2MHz
3MHz
imaginary voltage (V)
formation conductivity (S/m)

(B)

FIG. 20


Percentage error with respect to real mud conductivity
blue -- 400 KHz
red -- 2 MHz
magenta -- 3 MHz
400KHz
2MHz
3MHz
percentage error (100%)
formation conductivity (S/m)

(C)

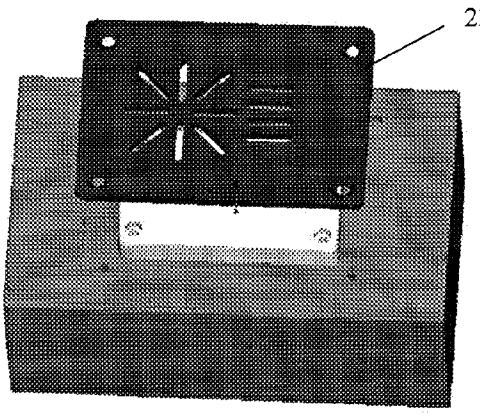


FIG. 23

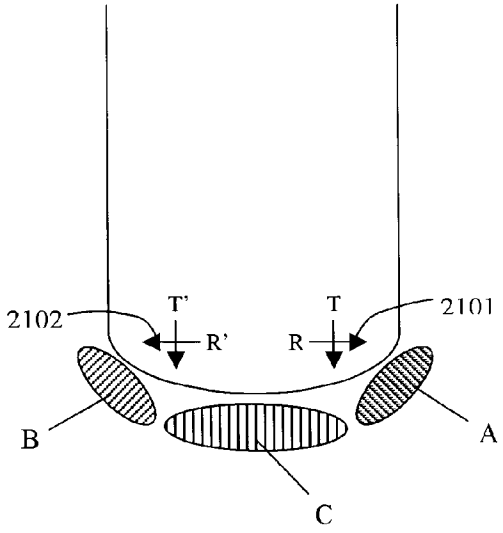


FIG. 21

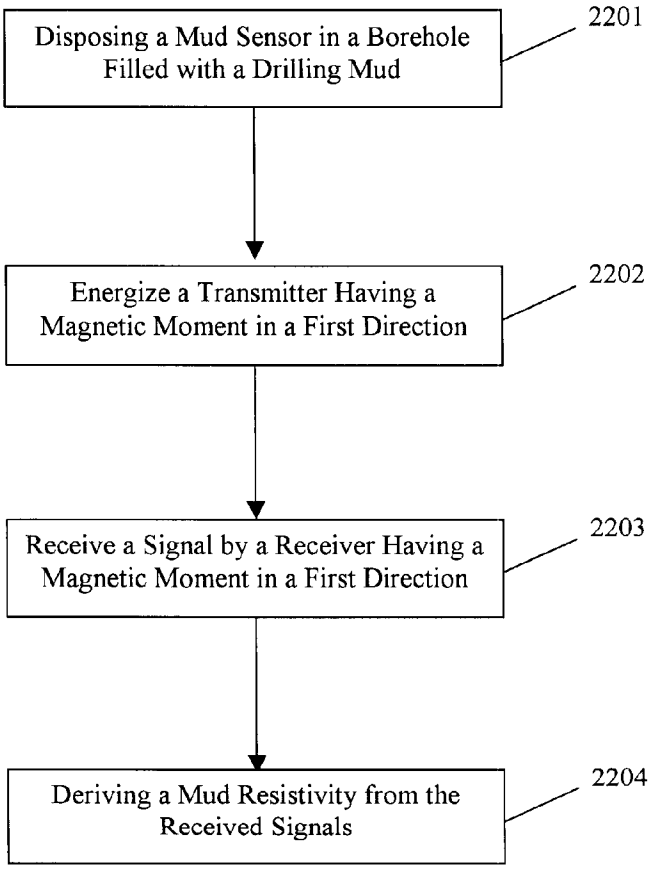

Disposing a Mud Sensor in a Borehole Filled with a Drilling Mud
2201
Energize a Transmitter Having a Magnetic Moment in a First Direction
2202
Receive a Signal by a Receiver Having a Magnetic Moment in a First Direction
2203
Deriving a Mud Resistivity from the Received Signals
2204

FIG. 22